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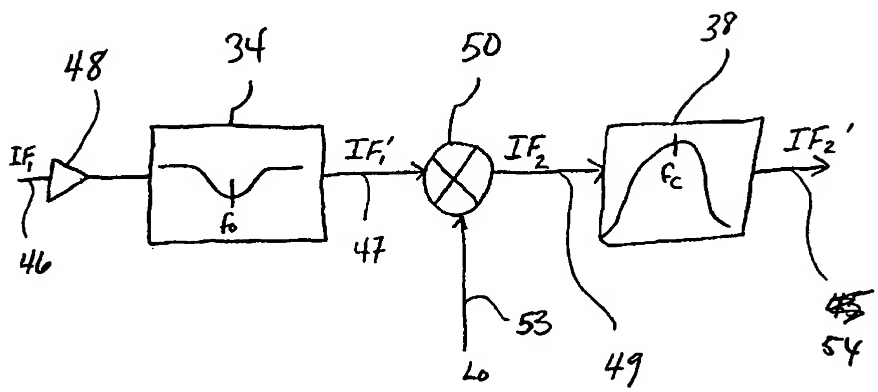
(54) Title: METHOD AND APPARATUS FOR ELIMINATING IN-BAND RIPPLE FROM BAND-PASS FILTER RESPONSES



(57) Abstract: A circuit produces a band-pass filter amplitude response with substantially reduced ripple in the pass-band. The circuit of the invention employs a band-pass filter circuit that can be optimized to meet the out-of-band rejection specification of particular application, and a complementary filter that has an amplitude response that when additively combined with the amplitude response of the band-pass filter produces an overall band-pass response that is substantially flat over the pass-band. The two filters are isolated from one another such that the two filter responses combine additively without interaction between them. An optional amplifier can also be coupled to the input of the complementary filter to offset insertion loss resulting from the combination of the two responses. For band-pass filters that produce a rounded in-band amplitude response, the complementary filter is preferably a shallow notch filter. One preferred embodiment of the shallow notch is a series RLC circuit. One preferred embodiment of the invention can be employed to the process of frequency up-conversion. The complementary filter is a series RLC circuit, the band-pass filter is one optimized to reject out-of-channel interference signal components, and a mixer for performing the up-conversion provides the isolation between the two filters.

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METHOD AND APPARATUS FOR ELIMINATING IN-BAND RIPPLE FROM BAND-PASS FILTER RESPONSES

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to band-pass filters, and more particularly to a circuit providing improved flattening of the in-band or in-channel amplitude response of band-pass filters while minimizing the degradation of the signal to interference ratio (S/I) or signal to distortion ratio (S/D) out-of-band and more particularly to the implementation of up-conversion of IF signals to RF channels in systems such as cable television.

Background of the Related Art

The processing of broadband multi-carrier signals presents a particularly rigorous and stringent context for signal processing circuitry such as filters. The television signal for example, which has a bandwidth on the order of about 5-6 MHz (in North America – NTSC TV systems and about 7-8 MHz in international PAL TV systems), is typically modulated on an IF frequency of 45.75 MHz (in NTSC systems and about 38.9 MHz in PAL systems) and then up-converted to a radio frequency (RF) carrier signal in the range of 50 to 1000 MHz or greater, to achieve frequency division multiplexing (FDM). In digital TV transmission, 64 or 256 level QAM modulation is used (6 MHz wide centered on an IF carrier of 44 MHz in North American – DOCSIS applications, and 8 MHz wide centered on an IF carrier of 36 MHz in international digital video broadcast – DVB applications). Applications which require the processing of broadband signals such as the broadcast and reception of television signals can present situations which require filters to pass only a small fraction of the total bandwidth (those frequencies fall within the pass band), while rejecting the rest of the frequencies over the total bandwidth (those falling within the stop-band). This is accomplished using a narrow band-pass filter.

Noise and image signals, as well as various undesired spurious signals, can be injected or generated at various points in processing (such as up-conversion), and thus band-pass filters are often called upon to reject (i.e. attenuate) such out-of-band

signals to significantly low levels, depending upon the sensitivity of the application. For example, even signals attenuated up to 60dB can still be perceived in received video transmissions. Thus, it is often critically important that any signals present other than the modulated signal on the desired carrier be sufficiently attenuated. This often requires band-pass filters to be very selective (i.e. ideally passing only that fraction of the total bandwidth that contains the base-band signal modulated on the frequency carrier of interest), with little or no loss of energy in the pass-band (i.e. low insertion loss), while meeting and maintaining the requisite measure of attenuation for all other frequencies in the stop-band. Moreover, because the fraction of the total bandwidth occupied by base band signals in broadband applications is so small relatively speaking (on the order of 1-2%), such filters must produce the requisite frequency response with a high degree of accuracy and must maintain that response over time (i.e. the response should not drift). Further, they must be relatively immune to RF noise from external sources, as well as from coupling between their own components. Finally, it is always desirable that the filters be inexpensive, and easy to manufacture with a high degree of repeatable accuracy, notwithstanding the stringent operational characteristics required of them.

Additionally, in modern digital communications systems there is an ever-increasing demand for low-cost up-conversion. Thus, it would be highly desirable to pass two (or more) digital TV channels (modulated with 64 or 256 level QAM) through one CATV up-converter to reduce the cost and size of Head-End equipment. This is particularly important in emerging cable TV services such as Video-On-Demand (VOD), where a large number of channels is required to transmit a large number of program titles to different customers simultaneously.

A general discussion of up-converters is found in commonly assigned US Patent Application Serial No. 09/574,707 entitled "Agile Frequency Converter For Multi-Channel Systems Using If/RF Level Exchange For Improved Noise Rejection," which is incorporated herein in its entirety by this reference. As discussed therein, a band-pass filter is employed in a typical two stage up-converter following the first up-conversion stage to an RF frequency to filter out side-band and L_O leakage components generated during the mixing process. As previously discussed the rejection to be provided by this band-pass filter is stringent, but a flat response in the

pass-band is also highly desirable. The requirement for a flat in-band response places additional burden on the design and performance requirements of such band-pass filters, particularly because a flatter in-band response comes at the expense of reduced selectivity.

The up-converters disclosed in the aforementioned application are typically designed to operate for one channel, but as previously discussed, it would be highly advantageous to process two or more channels using a single up-converter. To pass two digital channels through a signal up-converter for this application requires that the wide-band-pass filters have twice the bandwidth in the pass-band (i.e. 12 MHz (16 MHz for international digital video broadcast – DVB applications)), having a substantially flat in-band response while meeting the same stringent rejection specifications for the single channel filter.

There are known techniques for implementing band-pass filters for applications such as CATV, including certain improved tuned resonator topologies disclosed in related and commonly assigned U.S. Applications Serial No. 09/039,988 entitled "Magnetically Coupled Resonators for Achieving Low Cost Band-Pass Filters Having High Selectivity, Low Insertion Loss and Improved Out-of-Band Rejection," and Serial No. 09/408,826 entitled "Narrow Band-Pass Tuned Resonator Filter Topologies Having High Selectivity, Low Insertion Loss, and Improved Out-of-Band Rejection over Extended Frequency Ranges," each of which is incorporated herein in its entirety by this reference. **Fig. 1** illustrates a common amplitude response **10** for these and other band-pass topologies. The in-band portion of the response is typically rounded or curved rather than flat, peaking at the resonant frequency f_C. This unwanted deviation from the ideal flat in-band response is known generally as ripple. As out-of-band rejection is increased through a sharper roll-off of the response, ripple increases in magnitude. Uncorrected, this ripple causes significant amplitude distortion of the in-band signal.

Because applications such as CATV require such filters to deliver difficult to achieve out-of-band rejection relatively close to the pass-band (on the order of 65dB or greater), such performance typically comes at the expense of increased ripple. While this strict S/I or S/D specification cannot be compromised, reducing the ripple is nevertheless critical to maintaining the integrity of the in-band signal. Ideally, it is

highly desirable to flatten the response curve **14** over the 0.5 dB bandwidth **16,** suffering neither significant insertion loss through the elimination of the ripple, nor degraded out-of-band rejection near the pass-band.

One known prior art technique for eliminating the in-band ripple is to cascade multiple band-pass filters together, each having resonant frequencies slightly higher or lower than f_C, but that still fall within or just outside the pass-band of the desired response. This is also known in the art as staggered tuning. As illustrated in **Fig. 2**, staggering and combining the amplitude responses produces a response **20** that tends to have a flatter in-band response at the expense of some insertion loss **24** that is also experienced in the pass-band. More significant, however, is the fact that the skirts of the resulting response **20** are widened, which degrades the rejection of proximate interference signals such as f_I **12** by as much as 10 dB or greater from that achieved by the response **10** prior to flattening its ripple. For applications such as cable television, this loss in rejection is significant given the level of rejection that is required for the system. A further shortcoming of this technique is that it introduces a large and undesirable group delay differential among the various in-band frequencies.

Another known technique that could be implemented to produce a more desirable band-pass amplitude response is to synthesize a network to produce the desired response, rather than employing a resonator having ripple that must be flattened. However, this technique yields networks that are extremely costly and complex, such as higher-order filters, and still suffers from the required tradeoff between decreasing the ripple, while increasing the width of the response (thereby degrading rejection) and the group delay differential of the input signal.

Thus, those of skill in the art will recognize that there is still a need for a method and apparatus by which the in-band ripple of band-pass filter circuits is reduced, while not significantly reducing the out-of-band rejection of proximate distortion and image components, introducing significant insertion loss in the pass-band, or increasing the group delay differential among the various frequency components of the input signal.

SUMMARY OF THE INVENTION

It is therefore an objective of the invention to reduce the in-band ripple of a band-pass filter amplitude response without degrading the rejection of proximate interference components which the filter is designed to eliminate, and without introducing significant insertion loss or increasing the group delay differential of the transmitted signal.

It is another objective of the invention to achieve the flattened in-band response for band-pass responses that are rounded or curved, by combining a shallow notch filter response with the band-pass filter response in an additive manner.

It is a further objective of the invention to employ a simple series or parallel RLC circuit topology to implement the shallow notch filter.

It is yet another objective of this invention to reduce in-band ripple of a band-pass filter amplitude response used in the up-conversion of modulated base-band signals such as television signals to RF channel frequencies, while meeting the stringent out-of band rejection specified by such systems.

It is yet another objective of this invention to reduce the in-band ripple of a band-pass filter amplitude response used in the up-conversion of base-band signals such as television signals to RF channel frequencies where the up-converter is shared between two RF channels.

It is still further an objective to provide a generalized approach to substantially reducing ripple in band-pass filter responses of any type.

These and other objectives will be clear to those of skill in the art in view of the following Detailed Description of the Invention:

A first preferred embodiment provides a band-pass filter response that is substantially flattened in the pass-band. The first preferred embodiment employs a band-pass filter that has a curved characteristic, such as that of a tuned resonator topology, in additive combination with a complementary filter that is implemented as a shallow notch. The complementary filter in general is designed to have that amplitude response that when added to the response of the band-pass filter, offsets

and therefore substantially negates the ripple from the response of the overall circuit combination. The responses combine additively because they are isolated from interacting with one another by a circuit coupled between the two filters capable of providing such isolation. In the context of an up-conversion, a frequency mixer provides such isolation between the two filters. The shallow notch can be implemented as a series RLC circuit connected in shunt with the line, or as a parallel RLC circuit in series with the line. Employed in the context of a CATV up-converter utilizing a dual conversion approach, the complementary filter is tuned to the first IF frequency of a TV signal, and the band-pass filter is tuned to a second IF frequency of the up-converter. The input of the first filter is coupled to the source IF signal, and the output of the first filter is coupled to a first input of the mixer. The output of the mixer is then coupled to the input of the band-pass filter, which is tuned to the second IF up-conversion frequency. A second input to the mixer is coupled to a fixed frequency input provided by a local oscillator. An amplifier can be coupled between the source IF signal and the complementary filter input and used to boost the gain of the input signal to the input of the complementary filter to overcome insertion loss caused by the combination of the two responses. Because the mixer (either passive or active) isolates the signals at its terminals (except for small leakage signals), it provides the buffering function performed by the buffer of Fig. 3b.

The benefit of the first embodiment within the context of applications such as cable television up-converters are as follows: 1) the complementary filter is tuned to the much lower source IF frequency while the band-pass filter is tuned to the second IF (up-conversion) frequency, thereby eliminating the need to tune the series RLC circuit to frequencies that make the tolerances of the R, L and C components become dominant; 2) the band-pass filter can be designed to maximize selectivity without concern for the flatness of its in-band response; and 3) rejection of signals such as L_O leakage signals that do not pass through the first filter are therefore unaffected by the first filter response.

A second preferred embodiment of the invention, suitable for supporting dual-channel (or multiple channel) up-conversion applications employs a complementary filter tuned to the first IF frequency. This first IF frequency is centered in between the two staggered IF frequencies of each of the two channels. The output of this first filter

is coupled to the input of a mixer. The mixer up-converts the first IF frequency to a second IF frequency that falls in the center between two channels. The notch response of the complementary filter is chosen to flatten the response of the band-pass filter over 12 MHz (16 MHz for DVB applications). In this way, the flattened band-pass filter response can include two 6 MHz channels (similarly, two 8 MHz channels can be combined to form a 16 MHz wide dual channel). As described above, an amplifier can be placed in series with the source IF signal and the input of the complementary filter with sufficient gain to overcome the insertion loss that is generated through the combination of responses and the resulting loss of amplitude coinciding with the loss of ripple.

The preferred embodiment of the method of the invention includes the step of preconditioning an input signal with an amplifier and a first filter response, up-converting the preconditioned signal using a local oscillator signal and filtering the up-converted preconditioned signal with a second filter response designed to achieve the requisite rejection of unwanted distortion components of the up-conversion process, such that the resulting combination of the two responses results in a flat response in the pass-band while maintaining the requisite rejection specified for the system.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a conceptual representation of the amplitude response of a typical resonator-based band-pass filter.

Figure 2 is an illustration of the results obtained by prior art techniques for flattening the response of a resonator filter.

Figure 3a is a graphic representation of the goals to be achieved by the present invention.

Figure 3b is a conceptual representation of the fundamental basis of the present invention.

Figure 4a is a conceptual representation of the notch filter network of the present invention.

Figure 4b is a conceptual representation of a dual network implementation of the notch filter of Fig. 4a.

Figure 5a is a conceptual representation of the application of the present invention in the context of up-converting an IF input signal to an RF channel frequency.

Figure 5b is a conceptual representation of signal components generated by the up-conversion process, including the up-conversion of the notch filter response to the RF channel frequency.

Figure 6a is a measured amplitude response of a resonator circuit.

Figure 6b is a conceptual representation of the resonator circuit that produced the measured response of Fig. 6a.

Figure 6c is the measured group delay for the resonator circuit of Fig. 6b.

Figure 7a is the measured response of a shallow notch filter designed to flatten the pass-band of the band-pass resonator filter response of Fig. 6a.

Figure 7b is a circuit implementation of the shallow notch filter of the present invention producing the response of Fig. 7a.

Figure 7c is the measured group delay for the shallow notch filter of Fig. 7b.

Figure 8a is the measured response for the combined responses of Figs. 6a and 7a.

Figure 8b is a conceptual representation of the implementation of the present invention within a two-stage up-converter.

Figure 8c is the measured group delay for the present invention having the amplitude response of Fig. 8a.

Figure 9 is a measured response when the present invention is used to flatten the response of a band-pass filter over two 6 MHz channels.

DETAILED DESCRIPTION OF THE INVENTION

The following is a detailed description of the preferred embodiments of the present invention. **Fig. 3a** graphically illustrates the concept of adding a shallow notch filter response **30**, tuned to a frequency f_C, to a band-pass filter response **10** tuned to the same frequency. If the curvature and width of the notch response is properly specified, the ripple (i.e. the curved nature) of the band-pass response in its pass-band will be offset and thereby flattened by the notch. Further, if the right amount of gain is applied to the input signal to offset the reduction in amplitude created by the depth of the shallow notch, the pass-band response can be flattened without significant insertion loss. Most importantly, however, is the fact that the width of the notch can be controlled to limit the widening of the original response, thereby minimizing the loss of rejection of the out-of-band of distortion signal **12**. As illustrated, the new response **33** will be only insignificantly widened, and the degradation in the rejection is limited to a value on the order of 0.5 dB or less. Finally, the differential in band group delay introduced by the circuit is acceptably small and a significant improvement over prior art solutions is achieved.

Fig. 3b illustrates a conceptual representation of a circuit for implementing the graphically represented process of **Fig. 3a**. Shallow notch filter **34**, the complementary filter, is cascaded with band-pass filter **38** through isolation buffer **36**. The isolation buffer **36** is important because it ensures that the two filter responses are completely additive, thereby preventing the two networks from interacting with one another. It is this isolation that also provides the improved group delay differential of the output signal. Those of ordinary skill in the art will recognize that this basic concept, as illustrated by the circuit of **Fig. 3b**, can be extended generally to cover band-pass filters having characteristics in the pass-band other than curved. The network required to flatten the response of a generalized band-pass characteristic can be synthesized using known techniques once the complementary amplitude response necessary for flattening the characteristic has been specified. For band-pass responses that are other than curved, however, the response required to flatten the band-pass

response may not be a notch as is used in the exemplary embodiment of the invention disclosed herein.

Fig. 4a illustrates an implementation of the shallow notch filter **34** as a series RLC circuit. The values of capacitor C **40** and inductor L **44** control the width of the shallow notch response as well as the resonant frequency, while the value of resistor R **42** controls the depth of the notch. It should be noted that the depth of the notch is equal to (and therefore dictates) the insertion loss of the response characteristic resulting from the additive combination of the complementary notch filter response with the band-pass filter response. **Fig. 4b** illustrates the dual circuit or series implementation of **Fig. 4a**, which might be a better topological choice for particular applications. For example, if the shallow notch circuit of **Fig. 4a** is used in high frequency applications to flatten the in-band response of a band-pass filter such as those typically used following a mixer in the up-conversion of cable television signals, the tolerances of the components become predominant at the requisite resonant frequency on the order of 1 GHz. For example, if the capacitor has a tolerance of 5%, at 1 GHz this might represent a 25 MHz increase or decrease in the resonant frequency of the shallow notch **34**. When the bandwidth of a channel is only 6 MHz, this would be clearly unsatisfactory performance because it could not be guaranteed that the resonant frequency of the two filters would be nearly identical, which is required to achieve desired flattening of the combined response.

In high frequency applications such as cable TV, IF signals having a range of frequencies centered on about 44 MHz are up-converted to a range of channel frequencies between 50 MHz and 870MHz. To accomplish this, typically they are first up-converted to a frequency of about 1014 MHz and then down converted to their target channel frequency from there. This two-stage up-conversion process is described in related and commonly assigned US Patent Application Serial No. 09/574,707 entitled "Agile Frequency Converter For Multi-Channel Systems Using If/RF Level Exchange For Improved Noise Rejection," which is earlier incorporated herein in its entirety by reference. Application of the present invention within the context of such an up-converter is illustrated in **Fig. 5a**. The base-band signals (such as video and audio signals) that are to be up-converted are modulated on IF carriers and combined to form a composite IF_1 signal **46**. The shallow notch filter is tuned to

the frequency substantially at the center of the IF composite signal, which is about 44 MHz. The source IF_1 signal **46** to be up-converted is first amplified by optional amplifier **48** to provide sufficient gain to offset a relatively small amount of insertion loss resulting from the notch depth. IF_1 **46** is then passed through the shallow notch filter **34.** Resulting signal IF_1' **47** is then up-converted by mixer **50** as a function of local oscillator signal L_O **53**, which is typically a frequency of about 970 MHz. In this context, passive mixer **50** provides the isolation that is represented by buffer **48** of the general concept illustrated by **Fig. 3b**.

As illustrated by **Fig. 5b**, the first stage of the two-stage up-conversion produces an output IF_2 **49** made up of a number of frequency components, including upper and lower side-band components **45** and **56** respectively. Upper side-band component **45** has a carrier frequency equal to 970 MHz (the value of L_O)plus 44 MHz, which is approximately 1014 MHz. As discussed in the related patent application referenced above, only the upper side band component **45** is used. So lower side band **56** and other unwanted interference components such as leakage component **60** corresponding to L_O signal **53** must be rejected by band-pass filter **38** to achieve a minimum of 65 dB of rejection with respect to the signal of interest. To accomplish this, band-pass filter **38** is substantially tuned to 1014 MHz when handling one channel. If handling two channels, band-pass filter **38** filter can be tuned up or down by 3 MHz so that its resonant frequency falls between two of the 6 MHz channels. As described in the related application above, the up-conversion process then continues with a second conversion stage that employs a second mixer to down-convert the upper side band component **45** to place it within its assigned RF channel frequency range.

Fig. 5b further graphically illustrates what happens to the signals generated during the up-conversion process when the input signal is processed through shallow notch filter **34** of **Fig. 5a**. The source input signal IF_1 **46** is essentially pre-distorted by the response of notch filter **34** prior to the up-conversion process, and this pre-distortion accompanies the signal to the up-converted frequency. The pre-distorted lower side-band component **56** is rejected by band-pass filter **38**, as is L_O leakage component **60**. It should be noted that L_O leakage component **60** only sees the band-pass filter (it is not pre-distorted by notch filter **34**), so it sees the rejection provided

by the band-pass filter alone, unaltered by the overall combination of the two filter responses. However, the output signal IF_2' **45** is subject to the flat in-band response created by the additive combination of the two responses as desired.

The preferred embodiment provides important advantages. First, by implementing the complementary filter prior to the mixer, it is can be tuned to a considerably lower frequency than the band-pass filter. This renders the implementation of the shallow notch filter simple and easy with inexpensive off-the-shelf components, notwithstanding the requirement that the filter be accurately tuned to ensure that the ripple is offset properly. Those of skill in the art will recognize that the two filters are designed to offset pass-band ripple when tuned accurately to a specific frequency. If either or both filters are too far removed from their designed resonant frequencies, the result of their additive combination will not be as desired.

Second, the band-pass filter of the invention can be designed with an additional degree of freedom. The band-pass filter can now be designed to maximize stop-band rejection virtually without concern for flatness of its response in the pass-band. This means that the band-pass filter can be reasonably inexpensive to manufacture, yet the up-converter will meet the stringent rejection specification of systems such as cable television while having a substantially flat in-band response with virtually zero impact on the level of rejection.

Finally, signals entering the invention subsequent to the complementary filter are not affected by the combined response, but only see the maximal rejection provided by the band-pass filter of the invention.

The following is an actual design example that illustrates a specific implementation of the present invention, as well as the methodology of the present invention. Those of skill in the art will recognize that this methodology can be applied to the more generalized embodiment as well. **Fig. 6a** is a measured response for a band-pass filter that is a cascaded filter employing two of the triple resonators substantially as disclosed in accordance with **Fig. 34a** of previously referenced U.S. Application Serial No. 09/408,826, and one dual resonator circuit substantially as shown in **Fig. 32a** also of that application. **Fig. 6b** is a simplified representation of the band-pass filter **60**, which has triple resonator stages **60a** and **60b**, cascaded with

dual resonator stage **60c**. The filter is designed to provide a response that yields optimal rejection of the unwanted oscillator leakage component to meet and/or exceed the specification for the system. Those of skill in the art will recognize how to choose the appropriate component values to achieve the desired resonant frequency of 1014 MHz as indicated by point **61** on the amplitude response of **Fig. 6a**, as well as the required stop-band rejection. As previously discussed, the present invention permits the design of the band-pass filter to be optimized for rejection of the interference components without regard to the increased ripple that will result from such an optimization. The channel frequency range of 6 MHz, over which a flat response is desired, is shown by indices **62** and **63**.

The next step in the method of the present invention is to specify the notch filter response required to flatten the band-pass filter response of **Fig. 6a** over the 6 MHz pass-band (i.e. between points **62** and **63** respectively). This can be accomplished using commercially available synthesis software such as Genesys from Eagleware Corporation of Tucker Georgia. One of skill in the art need only specify the resonant frequency, the preferred circuit topology of the shallow notch (e.g. as illustrated in **Figs. 4a** or **4b**), and the pass-band frequency range. The notch depth can be made low priority because the insertion loss created by the notch depth can be significantly compensated for when necessary using the optional amplifier **48** of **Fig. 5a**.

Fig. 7a illustrates the measured amplitude response necessary to flatten the band-pass response of **Fig. 6a**. As indicated, the notch is tuned to 44 MHz. **Fig. 7b** illustrates the series RLC circuit synthesized to produce the response of **Fig. 7a**. The parallel network of capacitors C_a **72**, C_b **74** and C_c **76** were used to implement the network because a capacitor with a value of 29.5 pF with a 1% tolerance is not commercially available.

Fig. 8a is the measured response for the combined responses at the IF_2' signal output (**54**, **Fig. 5a**), which shows a virtually flat response over the pass-band of the band-pass filter. **Figs. 6c** and **7c** show the group delay for the band-pass **38** and notch **34** filters respectively. **Fig. 8c** illustrates the measured group delay for the combined response, which illustrates that not only is the combined group delay differential relatively small compared to prior art solutions, but the group delay itself has been

reduced relative to the measured group delay of the band-pass filter in isolation (**Fig. 6c**).

Thus, the method of the present invention permits the band-pass filter to be optimized for the rejection it must provide without being constrained by concern for the commensurate increase in pass-band ripple that occurs. The invention essentially pre-distorts and preconditions the input signal using the shallow notch and the amplifier, and then produces a flat pass-band response when combined with the band-pass response. The shallow notch does not affect the L_O leakage signal, because it only sees the band-pass filter. Thus, the rejection of that particular signal, along with other distortion and image signals generated by the passive mixer are isolated from, and thus are not affected by, the shallow notch. They are subject only to the response of the band-pass filter that has been optimized for stop-band rejection.

It should be noted that the measured values of the notch filter response shown in **Fig. 7a** do not equal precisely the peak ripple of the band-pass response because the in-circuit measurement using a high-impedance probe was measuring voltage while trying to display the result as power. Thus, if the measured values of the notch response are squared, they are approximately equal to the ripple of the band-pass response.

Fig. 9 illustrates how the present invention can be used to flatten the response over a wider pass-band, in this case over 12 MHz (i.e. two 6 MHz channels). To accomplish this, the notch is widened to flatten more of the band-pass response. The notch response and its circuit implementation are derived in the same manner as previously discussed for one channel. To apply this technique to permit an up-converter to handle two channels instead of one, the resonant frequency of the band-pass filter must be skewed up or down by about 3 MHz so that it straddles the frequency between two of the 6 MHz channels. The increased and flattened pass-band will then extend over the two channels, permitting the up-converter to up-convert signals to either of the two channel frequencies. Increasing the number of channels that an up-converter can handle will reduce the number of up-converters required for a system, thereby reducing the cost of the system significantly .

Those of skill in the art will recognize that the invention can also be employed to a single-stage up-conversion process as well.

WHAT IS CLAIMED IS:

1. An apparatus for providing a filter response having an input for receiving a source signal and an output, said apparatus further comprising:

a first filter having an amplitude response that has ripple over a predetermined frequency range, said first filter having an output coupled to the output of said apparatus;

a second filter having an amplitude response that, when additively combined with the amplitude response of said first filter, results in an amplitude response that is substantially flat over the predetermined frequency range, said second filter having an input coupled to the input of said apparatus; and

a mixer having a first and second input coupled to an input of said first filter and an output of said second filter respectively, said mixer for up-converting the source signal from a first frequency to a second frequency; and

wherein said up-converted source signal having said second frequency is subjected to an amplitude response that is the additive combination of said first and second filters.

2. The apparatus of Claim 1 further comprising an amplifier coupled between the source signal and the input of said second filter.

3. The apparatus of Claim 1 wherein said first filter comprises a tuned resonator band-pass filter having a resonant frequency substantially equal to the second frequency.

4. The apparatus of Claim 3 wherein said second filter is a shallow notch filter having a second resonant frequency substantially equal to the first frequency.

5. The apparatus of Claim 4 wherein said second filter comprises a series RLC circuit coupled in series between the input of said apparatus and the second input of said mixer.

6. The apparatus of Claim 4 wherein said second filter comprises a parallel RLC circuit coupled in shunt with the input of said apparatus and the input of said buffer mixer.

7. The apparatus of Claim 4 wherein:

the source signal is a base-band signal modulated on an IF frequency, the source signal occupying an IF channel band-width;

the source signal is up-converted to an RF signal occupying an RF channel bandwidth;

the second resonant frequency is substantially centered within the IF channel bandwidth; and

the first resonant frequency is substantially centered within the RF channel bandwidth.

8. The apparatus of Claim 7 wherein the predetermined frequency range is approximately equal to or greater than the RF channel bandwidth.

9. The apparatus of Claim 7 wherein:

the first resonant frequency is substantially centered between a first and second RF channel bandwidth;

the second resonant frequency is substantially centered between a first and second IF channel bandwidth ; and

the predetermined frequency range is approximately equal to or greater than the first and second RF channel bandwidth combined.

10. The apparatus of Claim 7 wherein said second filter comprises a series RLC circuit coupled in series between the input of said circuit and the input of said buffer circuit.

11. The apparatus of Claim **10** further comprising an amplifier coupled between the input of said apparatus and the input of said second filter.

12. The apparatus of Claim **11** wherein the gain of said amplifier substantially compensates for insertion loss experienced by the source signal relative to the amplitude response of said first filter.

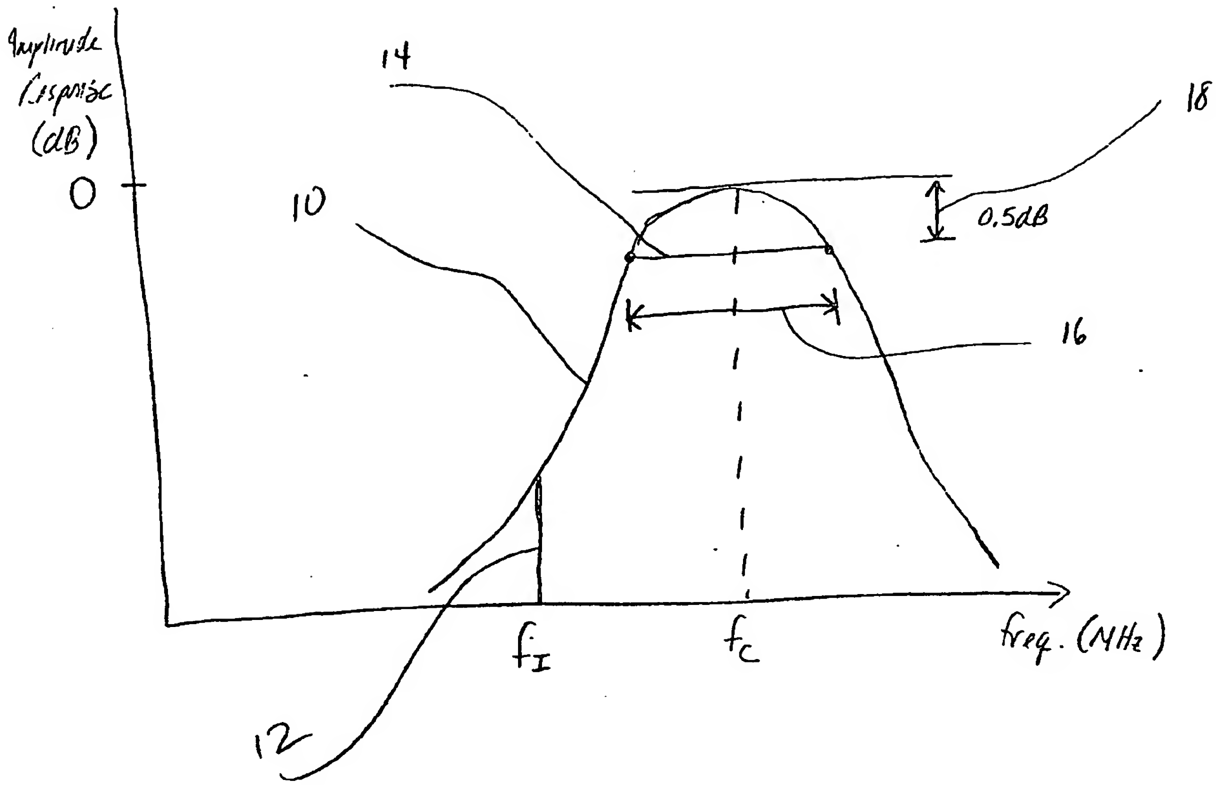


FIG. 1

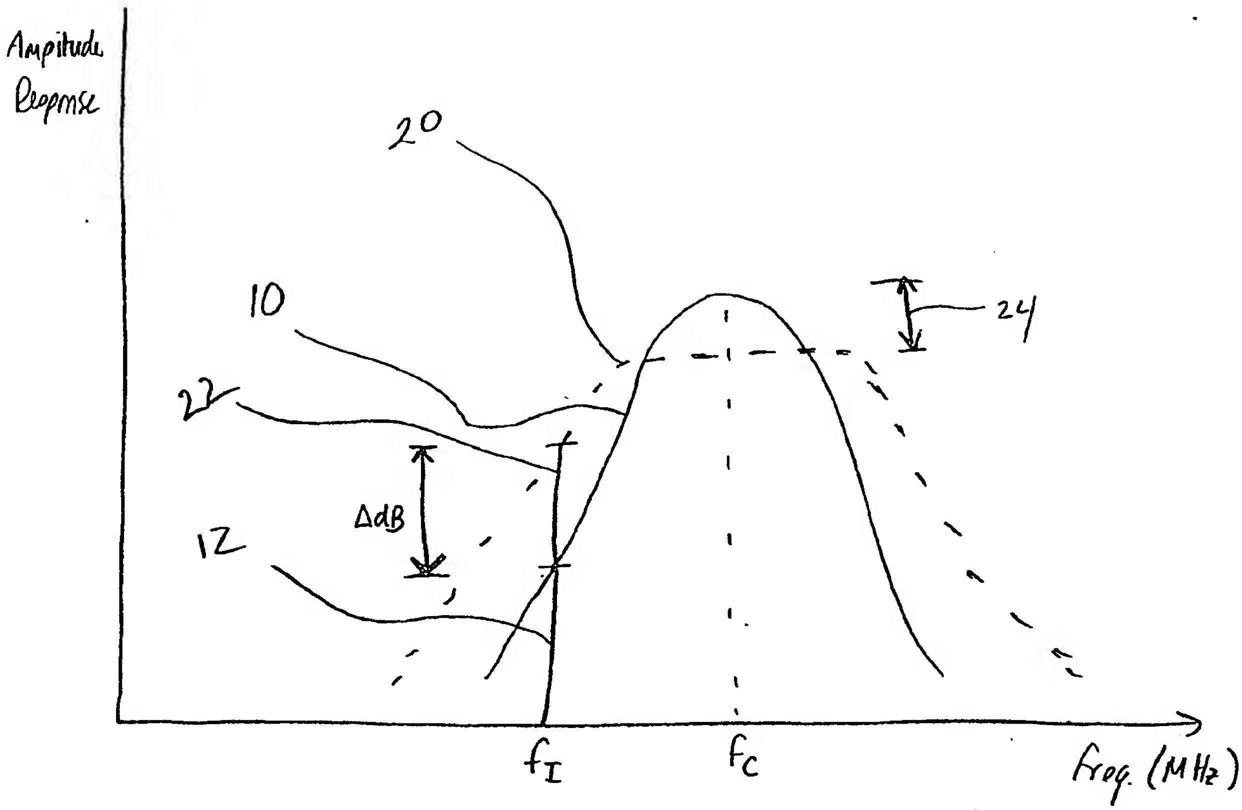


Fig. 2 (Prior Art)

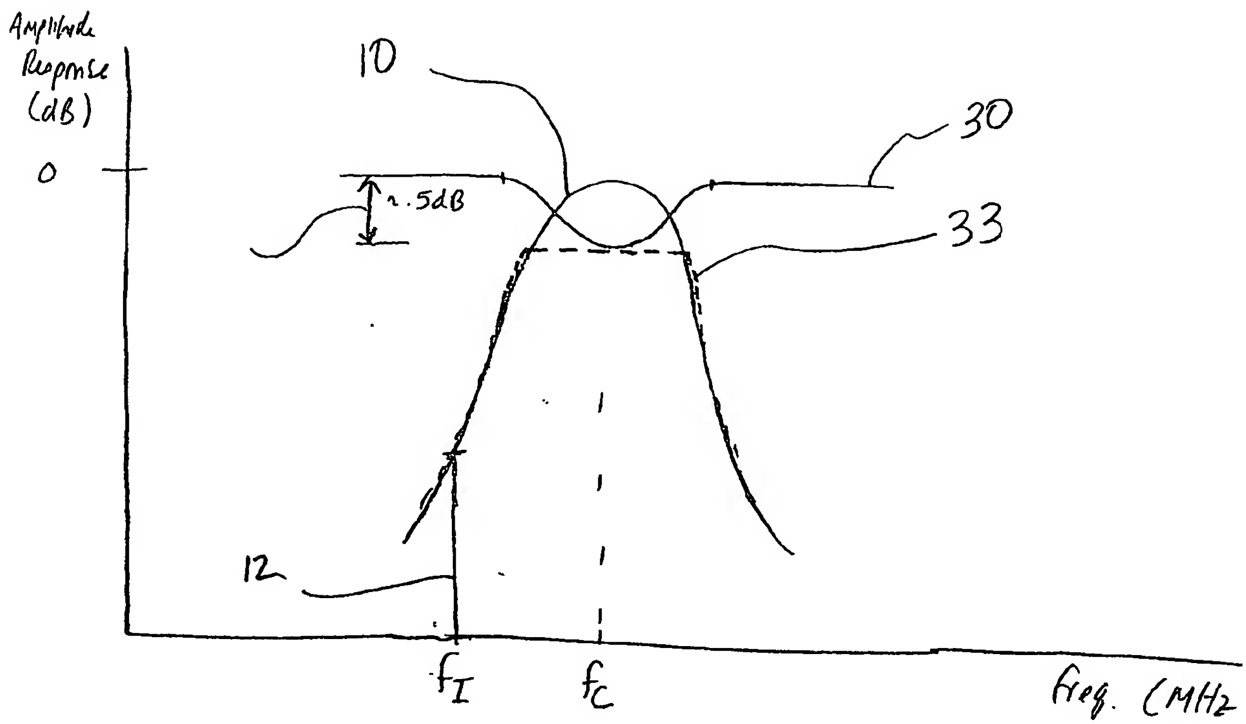


Fig. 3a

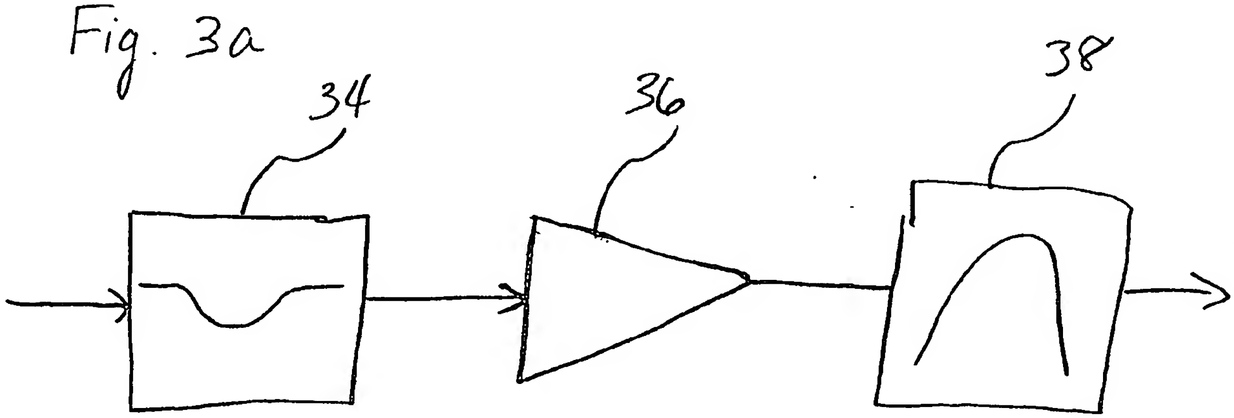


Fig. 3b

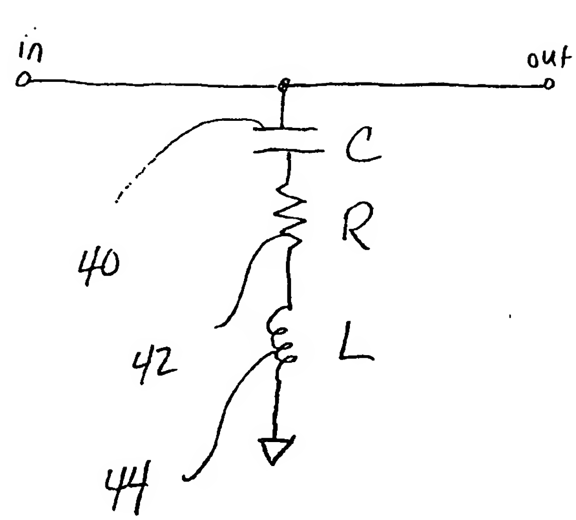


Fig. 4a

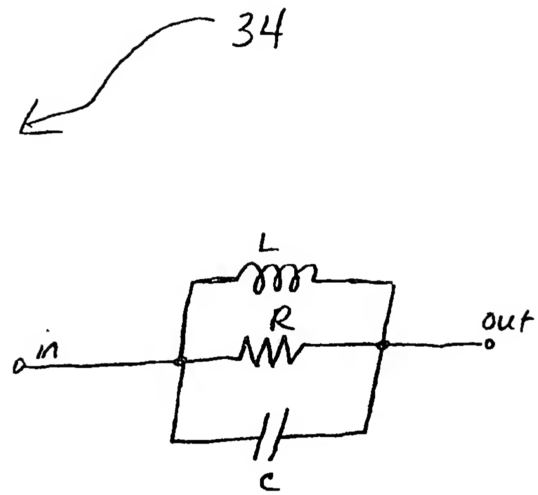


FIG. 4b

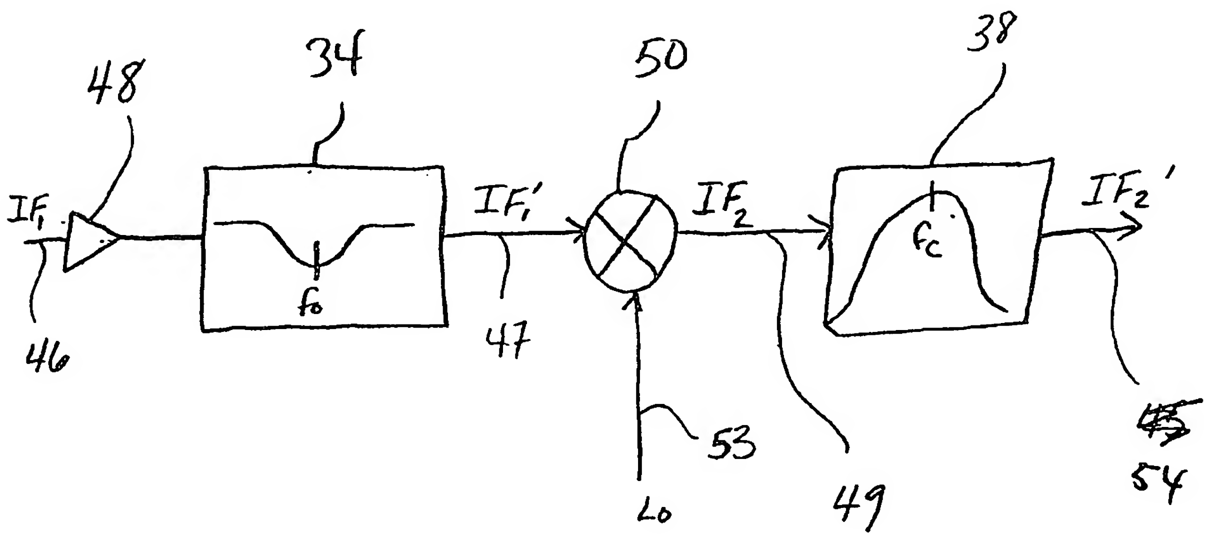


FIG 5a

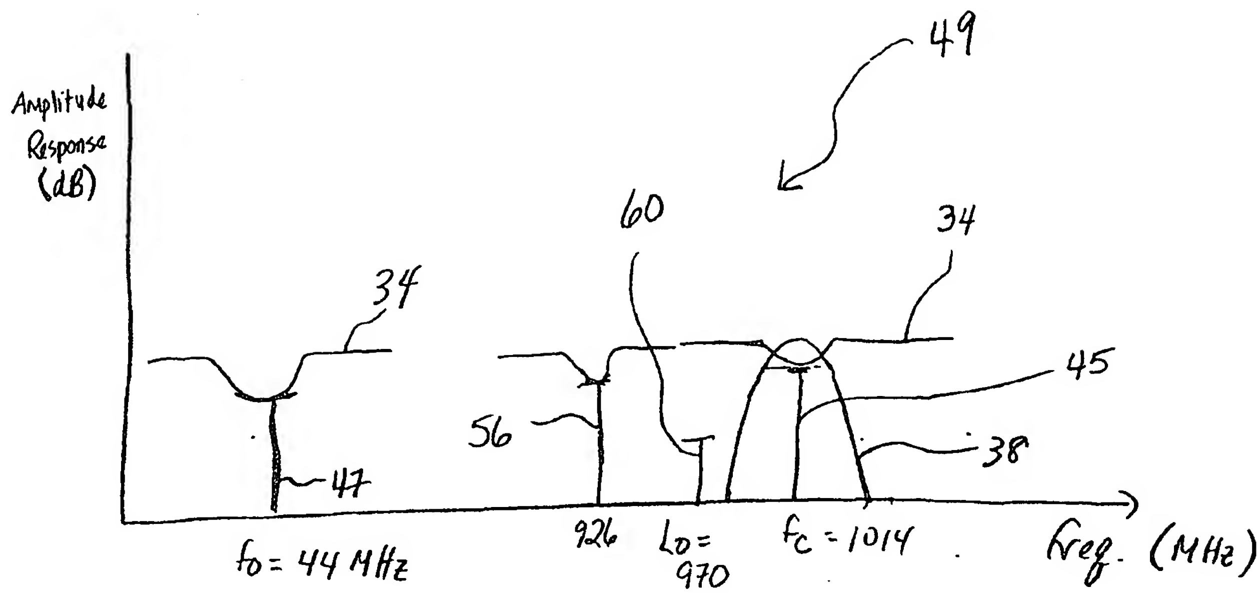

49
Amplitude Response (dB)
60
34
34
45
56
38
47
926
Lo = 970
fc = 1014
fo = 44 MHz
freq. (MHz)

Fig. 5b

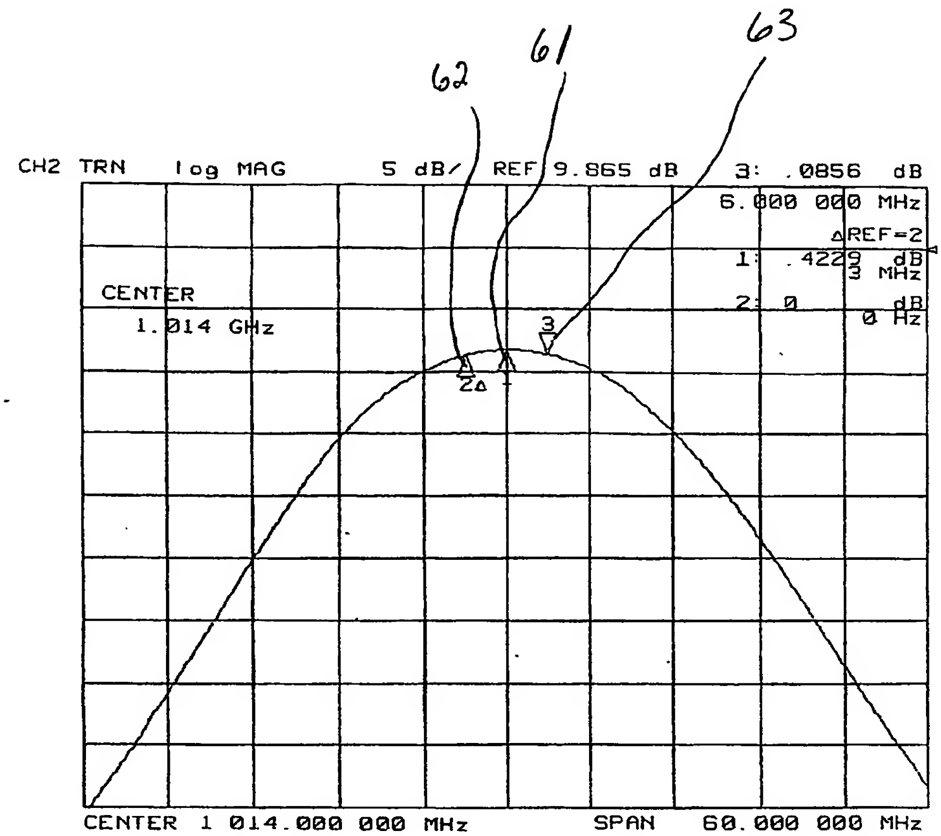

62
61
63
CH2 TRN log MAG 5 dB/ REF 9.865 dB 3: .0856 dB
6.000 000 MHz
ΔREF=2
1: .4229 dB
3 MHz
2: 0 dB
0 Hz
CENTER
1.014 GHz
3
2Δ
1
CENTER 1 014.000 000 MHz SPAN 60.000 000 MHz

FIG. 6a

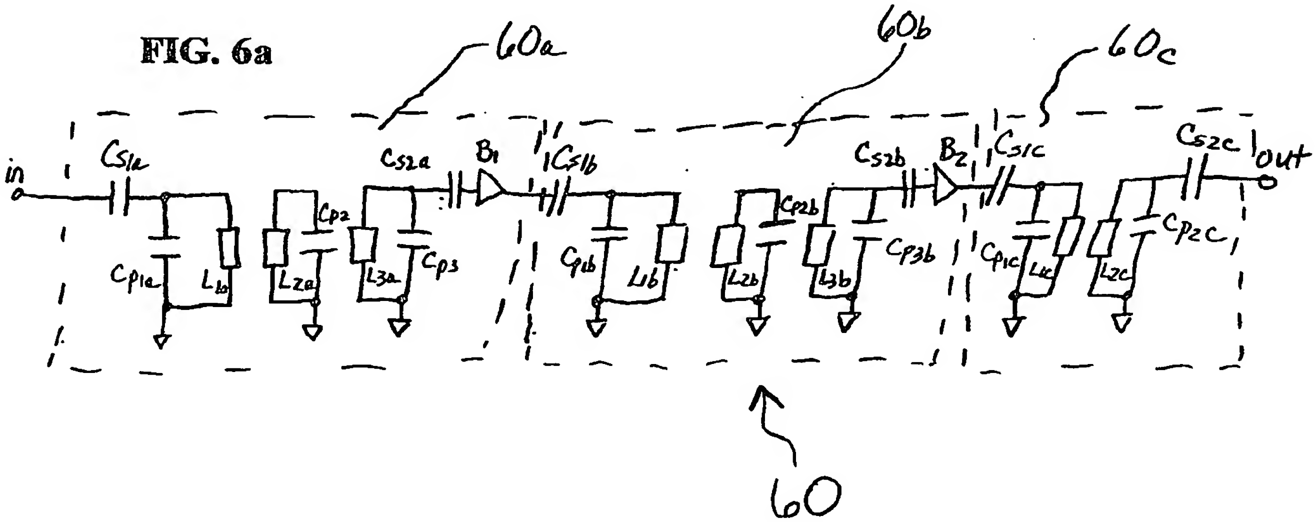
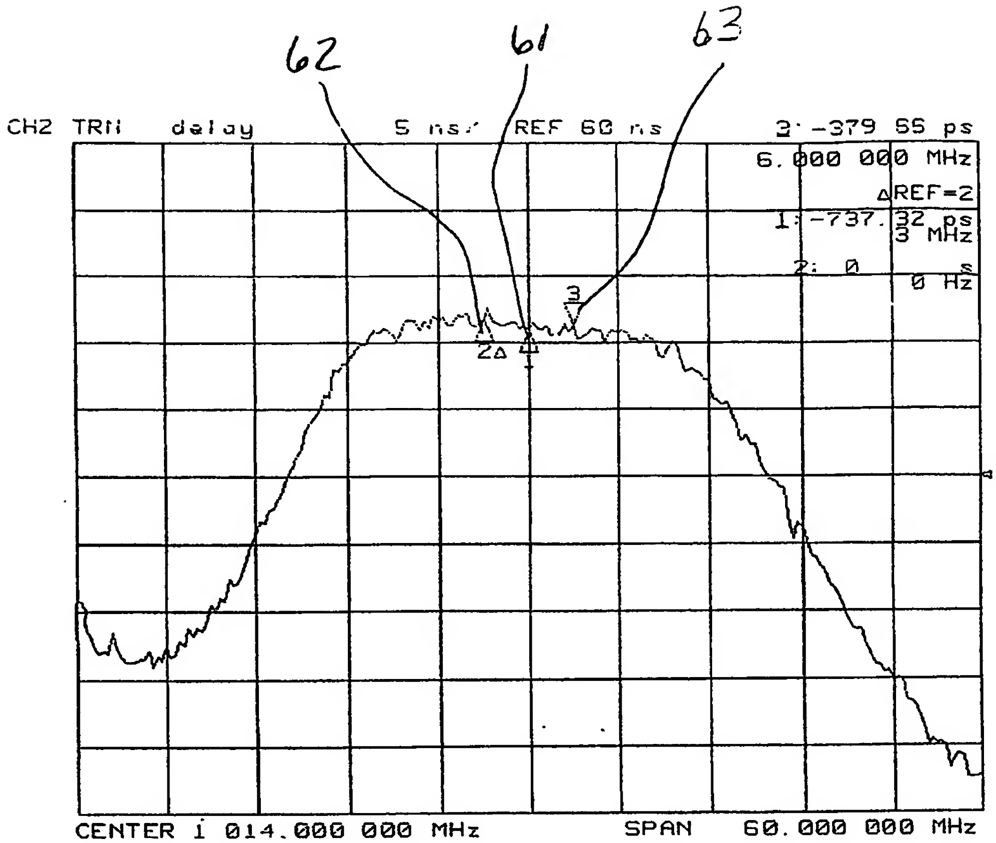

60a
60b
60c
in
out
Cs1a
Cs2a
B1
Cs1b
Cs2b
B2
Cs1c
Cs2c
Cp1a
L1a
L2a
Cp2
L3a
Cp3
Cp1b
L1b
L2b
Cp2b
L3b
Cp3b
Cp1c
L1c
L2c
Cp2c
60

FIG. 6b



62
61
63
CH2 TRN delay
5 ns/
REF 60 ns
3: -379 55 ps
6.000 000 MHz
ΔREF=2
1: -737.32 ps
3 MHz
2: 0 s
0 Hz
3
2Δ
CENTER 1 014.000 000 MHz
SPAN 60.000 000 MHz

FIG. 6c

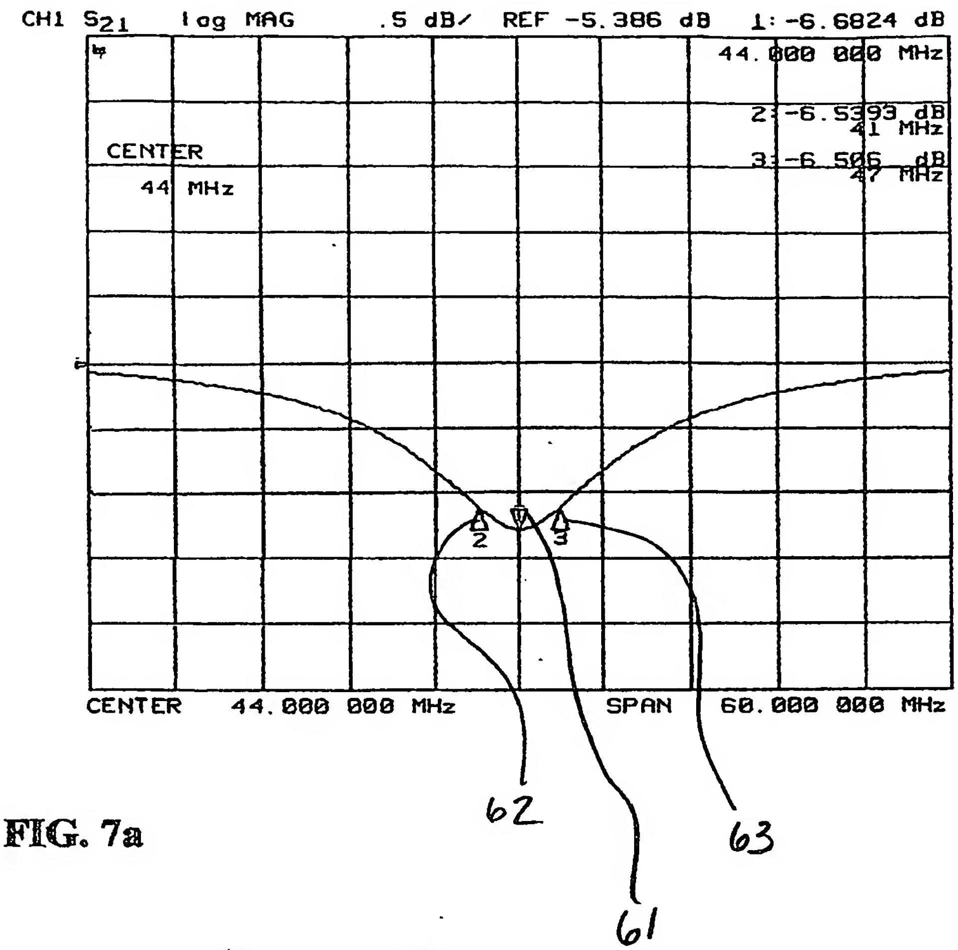

CH1 S21 log MAG .5 dB/ REF -5.386 dB 1: -6.6824 dB
44.000 000 MHz
2: -6.5393 dB
41 MHz
3: -6.506 dB
47 MHz
CENTER
44 MHz
2
3
CENTER 44.000 000 MHz
SPAN 60.000 000 MHz
62
63
61

FIG. 7a

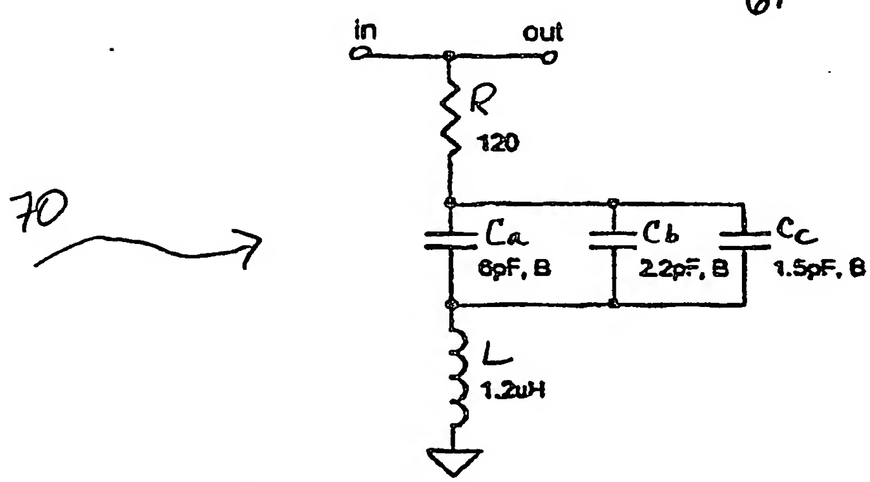

in
out
R
120
70
Ca
6pF, B
Cb
2.2pF, B
Cc
1.5pF, B
L
1.2uH

FIG. 7b

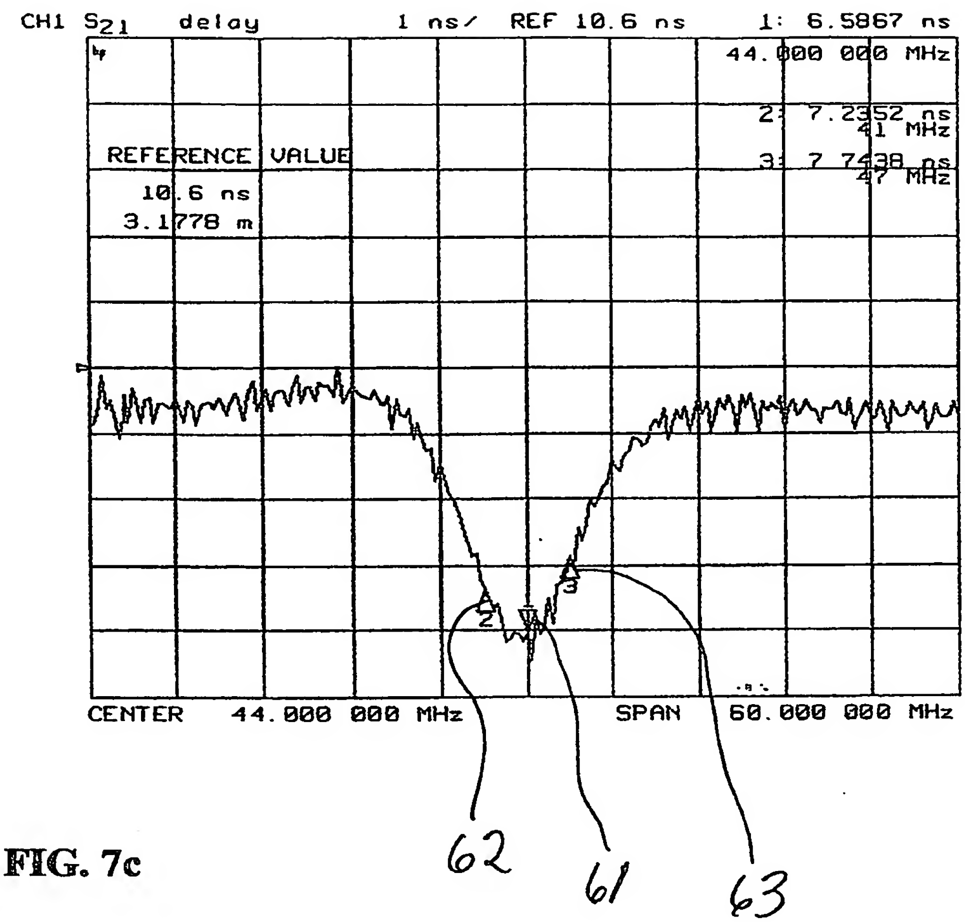

CH1 S21 delay 1 ns/ REF 10.6 ns 1: 6.5867 ns
44.000 000 MHz
2: 7.2352 ns
41 MHz
3: 7.7438 ns
47 MHz
REFERENCE VALUE
10.6 ns
3.1778 m
CENTER 44.000 000 MHz
SPAN 60.000 000 MHz
62
61
63

FIG. 7c

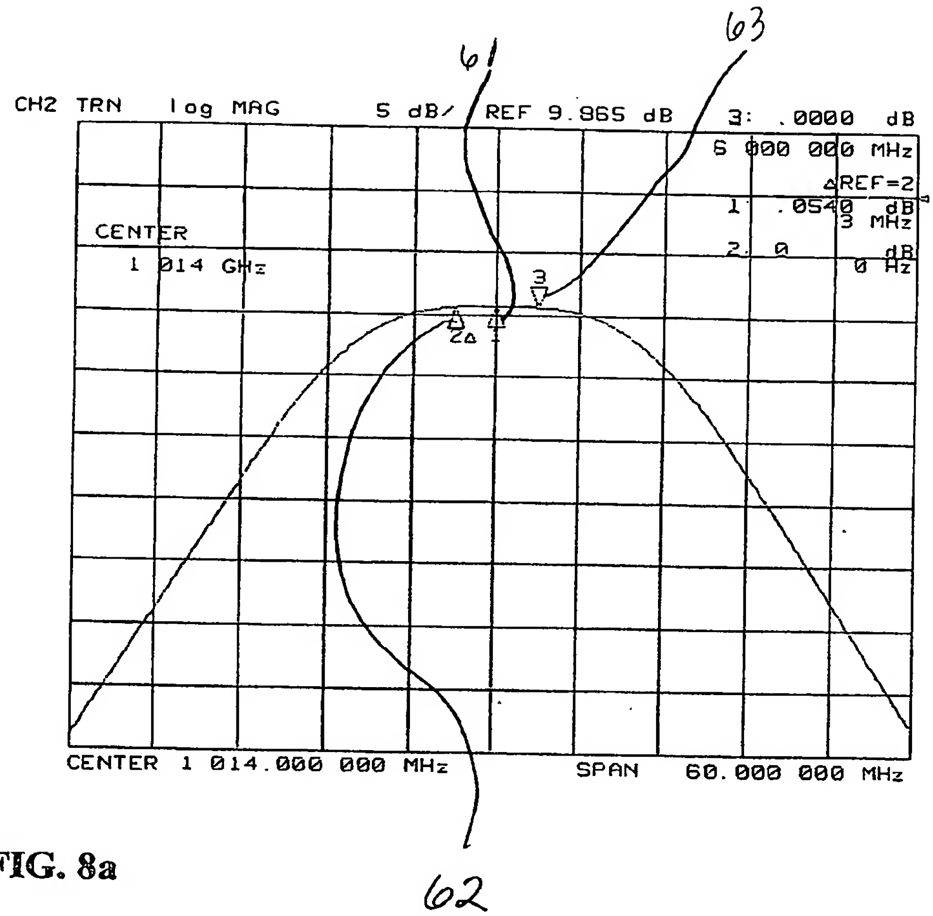

61
63
CH2 TRN log MAG 5 dB/ REF 9.865 dB 3: .0000 dB
6 000 000 MHz
ΔREF=2
1 .0540 dB
3 MHz
2 0 dB
0 Hz
CENTER
1 014 GHz
3
2Δ
1
CENTER 1 014.000 000 MHz SPAN 60.000 000 MHz
62

FIG. 8a

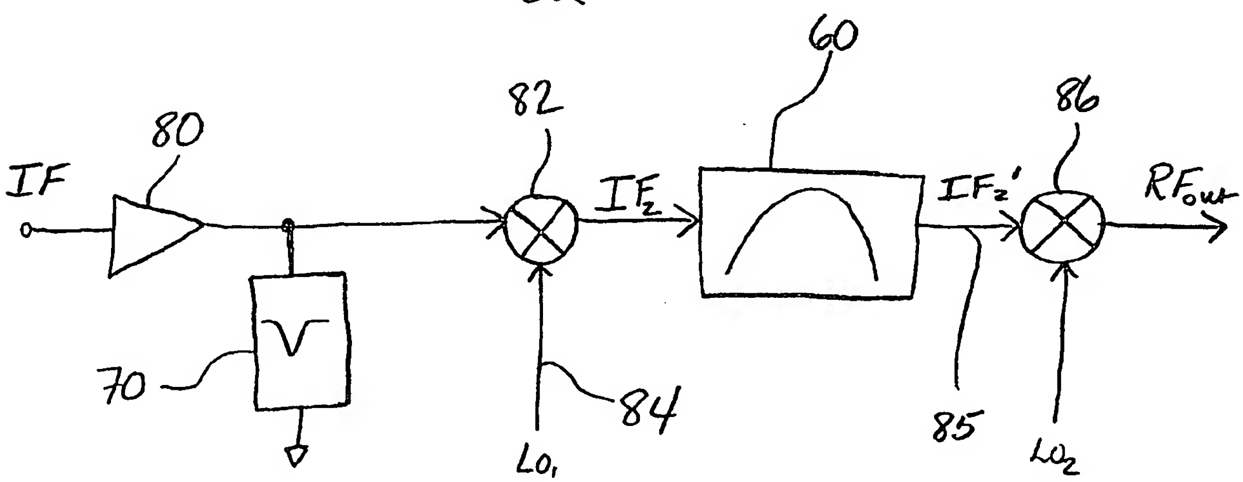

60
82
86
80
IF
IF2
IF2'
RFout
70
84
85
LO1
LO2

FIG. 8b

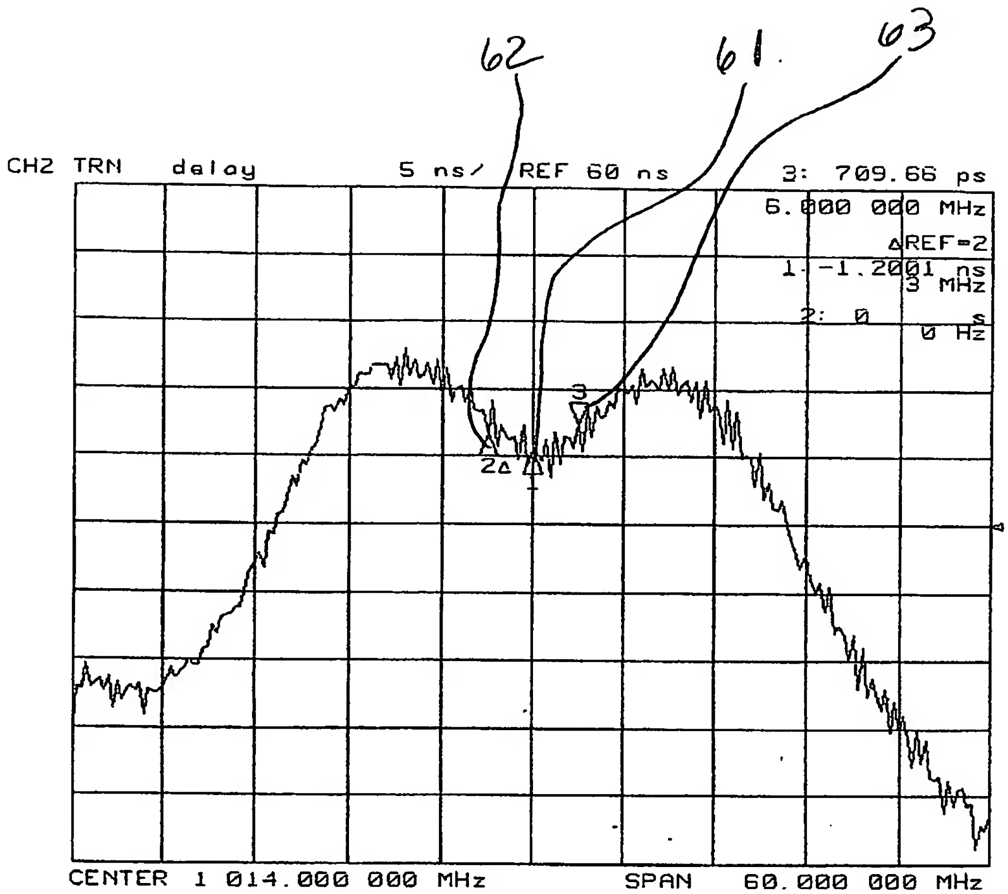

62
61
63
CH2 TRN delay
5 ns/ REF 60 ns
3: 709.66 ps
6.000 000 MHz
ΔREF=2
1: -1.2001 ns
3 MHz
2: 0 s
0 Hz
3
2Δ
1
CENTER 1 014.000 000 MHz
SPAN 60.000 000 MHz

FIG. 8c

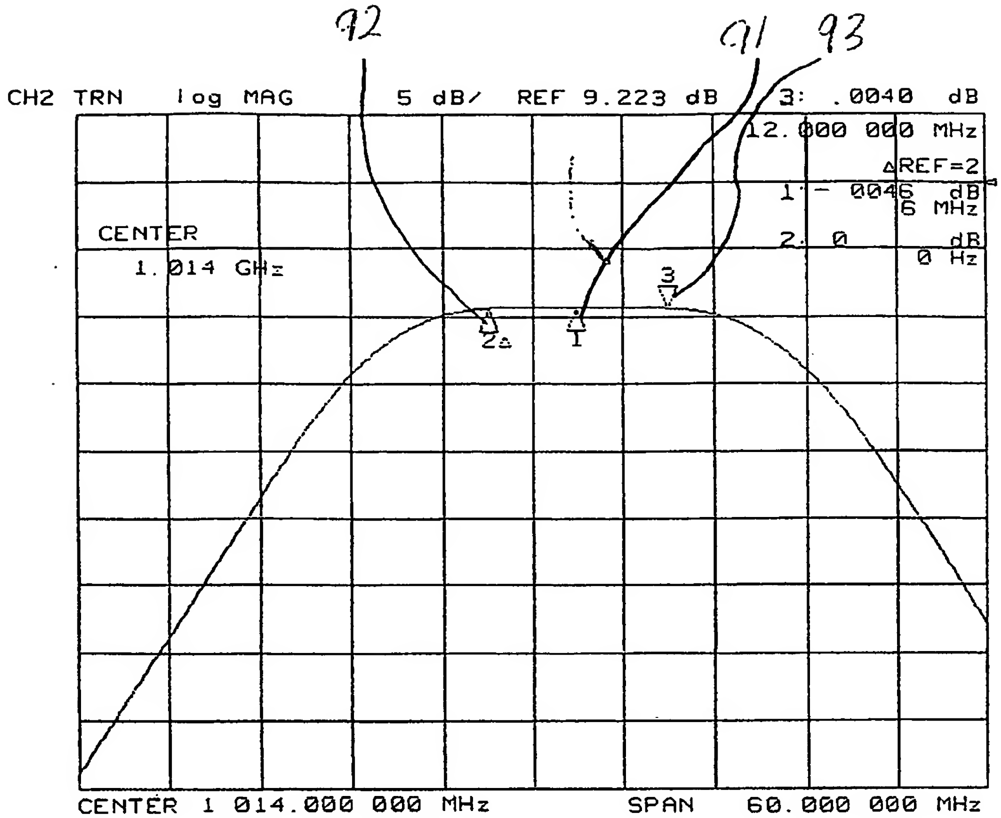

92
91
93
CH2 TRN log MAG 5 dB/ REF 9.223 dB 3: .0040 dB
12.000 000 MHz
ΔREF=2
1 - .0046 dB
6 MHz
2 0 dB
0 Hz
CENTER
1.014 GHz
3
2Δ
1
CENTER 1 014.000 000 MHz SPAN 60.000 000 MHz

FIG. 9a

FIG. 9b